FLIGHT CAPSULE CONTAMINATION PROBABILITY

FROM

VIABLE ORGANISM PENETRATION OF

BIO-BARRIER METEOROID HOLES

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INTRODUCTION

The Voyager Flight Capsule (F/C), designed to soft-land a
sterile instrument package on the Martian surface, will be en-
closed in a Bio-Barrier (B/B) to prevent contamination before
launch and in transit to Mars. Due to weight limitations, the
B/B cannot be made impregnable to meteoroids. It is also im-
practical to sterilize the entire vehicle (flight spacecraft and
F/C). Therefore, it is reasonable to assume that some concentra-
tion of Earth-originated viable organisms (V/O) will exist in the
B/B's external environment. The purpose of this report is to ex-
amine the probability that one of these V/Os will enter the B/B
through a meteoroid hole, producing a contaminated F/C.

The analytical approach used is a two-step process. First,
the physical damage to the B/B (and an associated thermal barrier)
is assessed using a NASA-MSC meteoroid impact model. Second, the
V/O concentration outside the B/B necessary to give a contamina-
tion probability of 10^{-4} (NASA-established) is determined.

Two V/O forms were considered in preliminary calculations:
1) large particle or dust forms where the V/O are unaffected by
conceivable external gas clouds; and 2) a form small enough that
the V/Os behave like gas molecules in an external gas cloud. The

latter form was investigated and rejected as a contamination threat for two primary reasons. First, a V/O will have a mass orders of magnitude larger than a gas molecule. Therefore, a tenuous external gas cloud would not be able to suspend a V/O and give it sustained mobility. Second, no credible evidence was found that indicated that a significant external gas cloud would accumulate. The molecules' thermal velocities and mean free paths dictate that the gas density outside the spacecraft will be extremely close to the interplanetary gas density.

The calculations, therefore, are based on dust-like or dust-borne V/Os being deposited on the meteoroid-perforated vehicle surface. The results are given in terms of the external V/O deposits that would be required to give the specified contamination probability.

Finally, the probability of finding these V/O deposit levels is assessed in terms of the likely number of V/Os that might be freed from the vehicle and redeposited on its surface. This assessment gives a measure of the real probability of contamination from this source.

INITIAL ASSUMPTIONS

The treatment of this problem requires a set of initial assumptions:

1) The F/C is sterile (no V/O inside the B/B) when the payload leaves the Earth's atmosphere;

2) The B/B is intact (no holes through which a V/O can enter) when the payload leaves the Earth's atmosphere;

3) A meteoroid impact sterilizes the impact area and, therefore, no V/Os will be carried inside the B/B by a penetrating meteoroid;

4) One V/O inside the B/B produces a contaminated F/C;

5) The probability that one V/O will enter the B/B during a 200-day trip to Mars must be less than 10^{-4}.

BARRIER CONFIGURATION

Figure 1 illustrates the B/B configuration used for the calculations in this report. Note that the B/B (0.020-inch aluminum) is enclosed in a thermal barrier (T/B) consisting of eight layers of 0.0005-inch aluminized mylar spaced one-eighth inch apart. The T/B, as will be shown, offers a significant amount of protection against V/O penetration of the B/B.
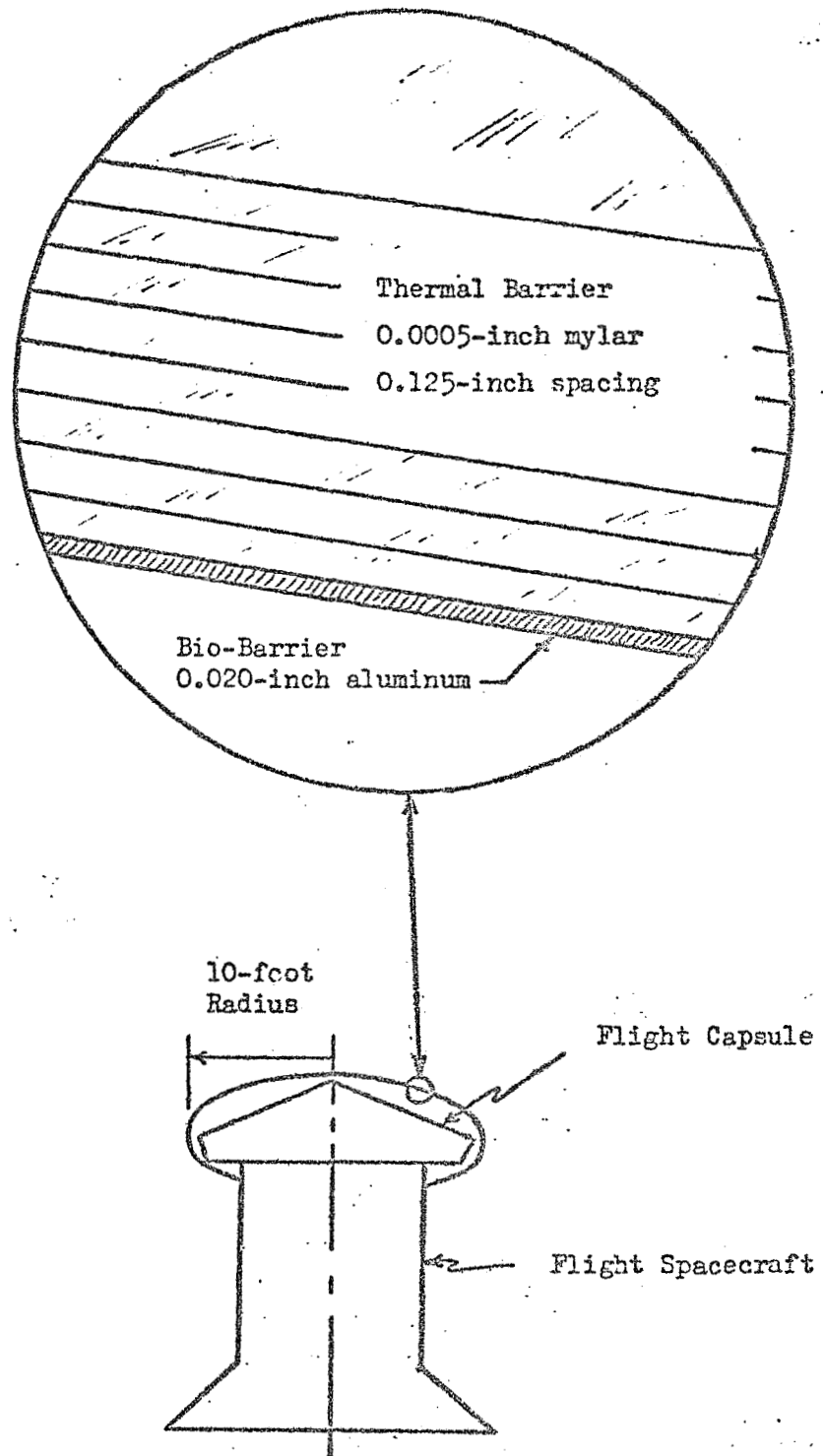
Thermal Barrier
0.0005-inch mylar
0.125-inch spacing

Bio-Barrier
0.020-inch aluminum

10-foot
Radius

Flight Capsule

Flight Spacecraft

Figure 1,   Barrier Configuration

METEOROID PENETRATION OF THE THERMAL AND BIO-BARRIER

Two meteoroid environment and penetration models are available, one from NASA-MSC and the other from JPL. These are described in the memorandum attached at the end of this report. Although the memorandum describes multi-layer B/B penetrations, previous analyses have shown that little difference is found between the results when the two models are applied to single-layer B/Bs.

Using the B/B specifications given in the previous section and the NASA-MSC model, the following results were obtained for a 200-day Earth-Mars mission.

Total area lost to punctures   = 0.512 in^2

Threshold (area of smallest holes)   = 0.0021 in^2

Average hole area   = 0.0022 in^2

Total number of holes   = 233

These results do not include the impact attenuation effect of the thermal barrier.

Figure 2 shows, qualitatively, four types of impact damage produced by meteoroids impacting perpendicular to the combined barriers. Types 1 and 2 do not penetrate the B/B. Type 3

represents a threshold penetration, while type 4 is a full pene-
tration. The total area lost to punctures is the sum of the areas
of the penetrating holes taken at the smallest cross-sectional
area in each hole.
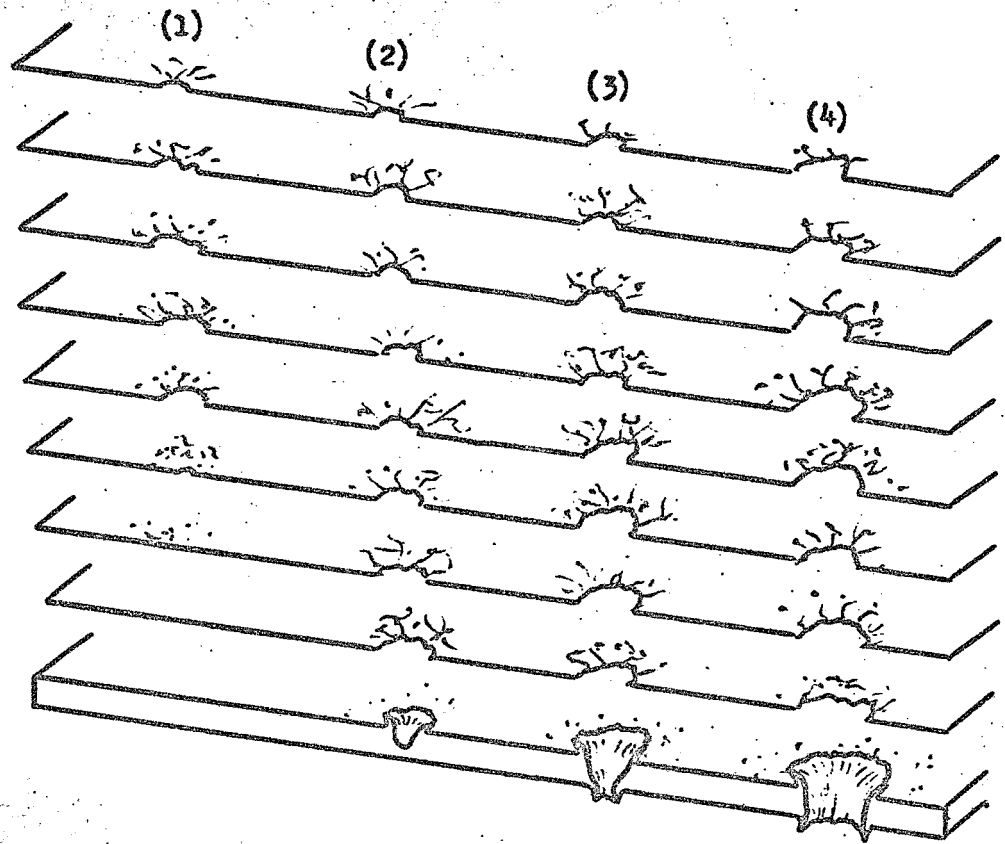
(1)   No B/B penetration

(2)   No B/B penetration

(3)   Threshold B/B penetration

(4)   Full B/B penetration

Figure 2.   Qualitative Perpendicular-Impacting
Meteoroid Penetrations

LARGE PARTICLE V/O CONTAMINATION PROBABILITY

This study treats each V/O as a large particle that is un-affected by gaseous diffusion principles. Four assumptions, in addition to those given previously, are used in the calculations:

1) The V/O are deposited uniformly on the external vehicle surface during the mission. In terms of the notation used in this report, if L is the total burden (number of V/O particles) deposited per square foot in 200 days, then $\frac{L}{200}$ V/O are deposited per square foot per day;

2) The area lost to punctures is a linear function of time. If $0.512/144 = 3.56 \times 10^{-3}$ square foot of the B/B is penetrated in 200 days, then $\frac{3.56 \times 10^{-3}}{200} = 1.78 \times 10^{-5}$ square feet are lost per day;

3) A V/O impacting on any of the T/B layers or the B/B ex-terior will stick to the surface and will not enter a B/B hole;

4) Where small probabilities are found, as they are in this report, the total contamination probability, P_c, is the sum of the contamination probabilities for the indivi-dual arriving V/Os.

Using these assumptions and T in days,

$$P_C = \int_0^{200} \text{(number of V/O deposited on total T/B surface}$$

per day) x (probability that one of these V/O

will enter an outer T/B hole leading to a

hole in the B/B) x (probability that a V/O

will travel through the series of holes in

the T/B and B/B and contaminate the F/C) x

dT.

If A is the total external area of the T/B, then rewriting the
above equation gives,

$$P_C = \int_0^{200} \left(\frac{L}{200} A\right) \left(\frac{T}{200} \frac{3.56 \times 10^{-3}}{A}\right) \left(P_p\right) dT.$$

The second term in the integral assumes that the holes in the
outer T/B layer have the same areas as the holes in the B/B. The
third term, P_p, will be referred to as the probability of penetra-
tion.

Assuming L, A, and P_p are constants, the indicated integra-
tion yields

$$P_C = 1.78 \times 10^{-3} L P_p .$$

Using $P_c = 10^{-4}$ as specified,

$$L\, P_p = 5.6 \times 10^{-2} \, . \qquad\qquad (1)$$

This states that the V/O deposit, L, required to produce the given P_c, is inversely proportional to P_p, the probability that a V/O will contaminate the F/C after entering an appropriate hole in the outer layer of the T/B.

The following cases determine P_p using a series of assumptions and give the corresponding values for L.

Case 1

Assume:

1) 233 holes, each of area $= 0.0022$ in^2 are created during the mission;

2) The penetrating meteoroids impact perpendicular to the T/B;

3) The holes in the outer T/B layer corresponding to the B/B holes also have area $= 0.0022$ in^2.

A V/O, entering an outer T/B hole, may be headed in any direction inside that layer. Since the B/B hole is one inch from the outer layer, solid angle considerations dictate that the V/O has

$$P_P = \frac{0.0022 \text{ in}^2}{2\pi(1)^2} = 3.5 \times 10^{-4}$$

or a probability of 3.5×10^{-4} of entering the B/B. Applying this P_P to Equation (1) gives

$$L = \frac{5.6 \times 10^{-2}}{3.5 \times 10^{-4}}$$

$$= 160 \text{ V/O per ft}^2 \text{ in 200 days.}$$

Case 2

Assume:

1) Same B/B holes and outer T/B holes as Case 1;

2) The penetrating meteoroids impact at random angles with respect to the T/B surface normal.

The second assumption gives longer average path lengths through the T/B as shown in Figure 3. Figure 4 gives the length of the tunnel through the T/B for oblique impacts where Θ is the angle between the meteoroid path and the T/B surface normal. Since all values of Θ have equal probability of occurrence, an average path length can be determined for impacts between $\Theta = 0°$ and $\Theta = 70°$. This disregards impacts in the $70°-90°$ range where meteoroid breakup prior to B/B contact is likely. This also produces a conservative
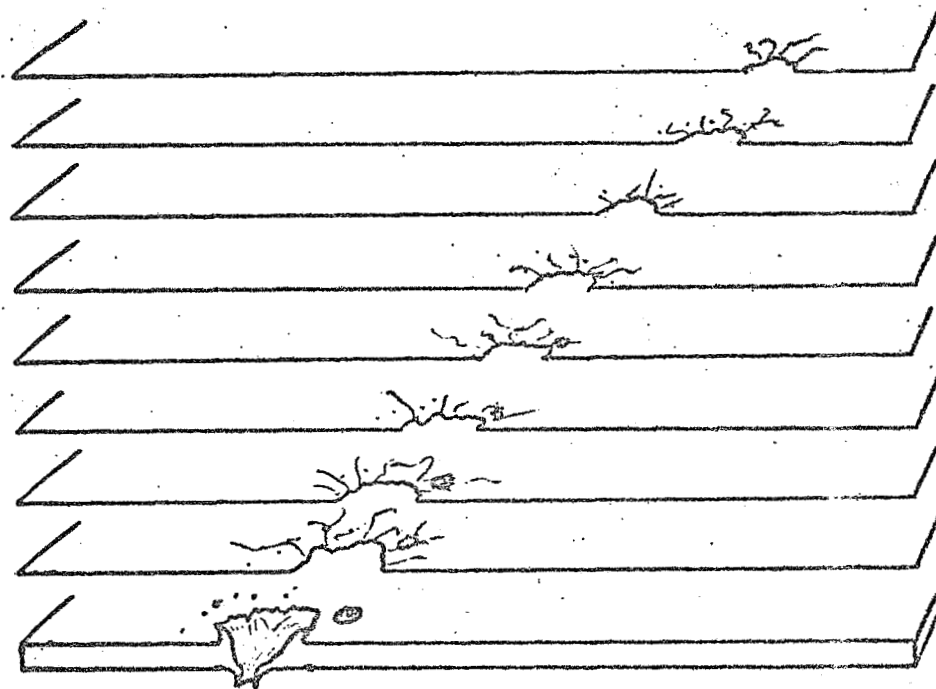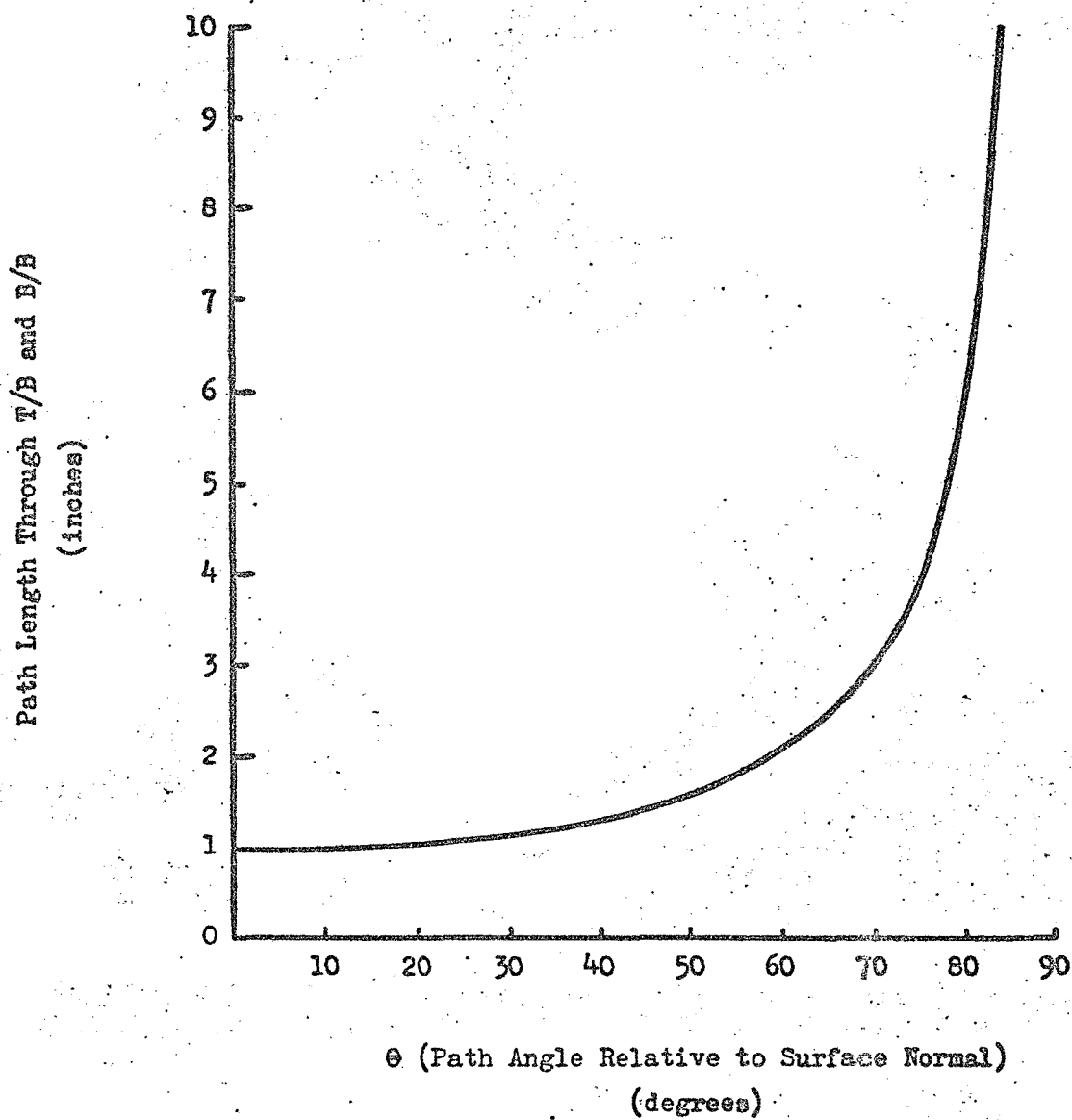
Figure 3.   Oblique Penetrating Impact

Figure 4.   Path Length Through T/B for Oblique Impacts

average path length of 1.5 inches through the T/B. The 70°-90° impacting meteoroids are still included in the impact figures, but their disproportionate weighting of the average path length is not included. Using 1.5 inches for the path length from the T/B entrance to the 0.0022 in^2 B/B hole gives

$$P_p = \frac{0.0022 \ in^2}{2\pi (1.5)^2 \ in^2}$$

$$= 1.6 \times 10^{-4}$$

and from Equation (1),

$$L = \frac{5.6 \times 10^{-2}}{1.6 \times 10^{-4}}$$

$$= 350 \ V/0 \ per \ ft^2 .$$

Additionally, the average angle between the plane of the B/B hole and the T/B tunnel is 45°. Therefore, the effective B/B hole area is reduced to 0.707 times its measured area when viewed through the T/B tunnel. This gives.

$$P_p = \frac{(0.0022) \ (0.707) \ in^2}{2\pi (1.5)^2 \ in^2}$$

$$= 1.1 \times 10^{-4}$$

and

$$L = \frac{5.6 \times 10^{-2}}{1.1 \times 10^{-4}}$$

$$= 510 \text{ V/O per ft}^2.$$

At larger values of θ, a combination of the crater and its hypervelocity lip may shield the B/B hole entirely from the associated T/B tunnel. However, any quantitative treatment of this effect would be speculative at this time due to the inexactness of hypervelocity cratering theory.

Case 3

This case incorporates T/B impact attenuation effects into the Case 2 results. The first two cases assumed that the B/B penetration area was not reduced by the T/B. However, the eight 0.0005-inch mylar layers in the T/B give an additional 0.004-inch layer of protection to the B/B. The reference given below states that more than twice as much protection against penetration is afforded by a spaced-layer shield compared to the same mass of material in one layer. As an approximation, then, the mylar layers are equivalent to an additional 0.010-inch of aluminum in the B/B, giving an effective thickness of 0.030 inch. Data obtained for 0.030-inch aluminum

NASA SP-78, The Meteoroid Environment and Its Effects on Materials and Equipment, W. A. Cosby and R. G. Lyle, 1965.

using the NASA-MSC meteoroid model indicate that the 0.030 barrier will lose only 0.45 of the area lost by the 0.020 barrier. This reduces the probability that a V/O will enter an outer T/B hole leading to a hole in the B/B to 0.45 times the previously assumed value. Using this factor in the original P_C equation yields

$$P_C = 8.0 \times 10^{-4} \, L \, P_P$$

and Equation (1) becomes

$$L \, P_P = 0.125 .$$

Using $P_P = 1.1 \times 10^{-4}$ from Case 2,

$$L = 1140 \text{ V/O per ft}^2 .$$

Case 4

The first three cases assumed that the holes in the outer
T/B layer have the same area as the B/B penetration holes. How-
ever, analysis of the NASA-MSC meteoroid model indicates that an
average B/B-penetrating meteoroid will have a diameter of approxi-
mately 0.006 inch. This gives a T/B layer thickness/particle dia-
meter ratio of 0.083 and the T/B layer penetrations fall into the
thin-plate penetration regime discussed in the reference given in
Case 3. This reference states that, under these conditions, the
hole area is approximately the same as the projectile cross-section
area. Therefore, the average B/B-penetrating meteoroid will pro-
duce a hole having area equal to

$$\pi r^2 = \pi (0.003)^2$$

$$= 3 \times 10^{-5} \text{ in}^2 .$$

In addition, the B/B crater material ejected back in a cone
along the impact path will be trapped by the intervening T/B lay-
ers, leaving the outer T/B hole relatively undisturbed. There-
fore, the vulnerable external T/B area is reduced to $3 \times 10^{-5} \text{ in}^2/$
$2.2 \times 10^{-3} \text{ in}^2 = 1.4 \times 10^{-2}$ (average external hole area/average B/B
hole area) times its previously assumed value. This affects the

second term in the original P_C equation and, when this alteration

is carried through the Case 1 to 3 assumptions, gives

$$L = \frac{1}{1.4 \times 10^{-2}} \times 1140$$

$$= 81,000 \text{ V/0 per ft}^2,$$

necessary to produce $P_C = 10^{-4}$.

SUMMARY OF LARGE PARTICLE V/O CASES

Table 1 summarizes the results of the four cases presented.

Table 1

Summary of Large Particle V/O Contamination Cases

Case	L*	Assumptions				
		Perpendicular Impacts	Oblique Impacts	T/B Impact Attenuation	Outer T/B Penetration Area = B/B Penetration Area	Outer T/B Penetration Area = 1.4×10^{-2} B/B Penetration Area
1	160	X			X	
2	510		X		X	
3	1,140		X	X	X	
4	81,000		X	X		X

* V/O per ft^2 in 200 days

V/O SOURCES AND PROBABLE 200-DAY DEPOSITS

The contamination probability discussed in the four cases in this report dependson V/O deposition on the T/B surface during the mission. No V/O sticking to the surface at the start of the mission poses a contamination threat until it is dislodged or freed from the surface by some impulsive force and subsequently impacts on the T/B under the influence of gravitational, and possibly electrostatic, forces.

It has been estimated that 10^5-10^6 V/Os per square foot will be on the exterior of the vehicle at launch. This is based on the expected clean-room environment, handling, and decontamination prior to launch. Only a portion of these V/Os will be loosely deposited on the surface. The remainder will be stuck to the surface or imbedded in the surface in such a way that they will not be dislodged during the mission. However, to arrive at a conservative estimate of the contamination risk, it is assumed that all of these V/Os are loosely bound or become loosely bound during the mission.

Using Case 4 assumptions, at the lower limit, 10^5, eighty percent of the external V/O may be released and redeposited on the surface without exceeding $P_c = 10^{-4}$. At the upper limit, 10^6, eight percent must be freed and redeposited to give $P_c = 10^{-4}$ with the same assumptions.

Since the V/Os start on the vehicle's surface, it is logical to assume that if the vehicle acquires a charge, the V/Os will acquire charge of the same sign. Therefore, a charged V/O from the vehicle will be repelled and lost. If all V/Os were charged, therefore, P_c would be essentially zero, since L would be extremely low.

However, if all of the freed V/Os are neutrally charged, they will be attracted toward the vehicle by the associated gravitational fields. Assuming a 10^4 kilogram (22,000 lb) total vehicle weight, a V/O at three meters from the vehicle's C.G. requires a velocity of only 0.67 cm per second to escape from the vehicle's gravitational field. At lower velocities, a V/O will orbit the vehicle or follow a ballistic trajectory across its surface.

During the mission, the base of the spacecraft (opposite the F/C) will be pointed toward the Sun. The solar radiation, particularly ultraviolet, will sterilize this end and exposed side areas during the mission. Therefore, the V/Os that pose a threat will in all likelihood be those that reside on the T/B at the start of the mission. Taking into account such things as meteoroid and mid-course, maneuvering-induced shock and vibration levels in the T/B, it appears likely that the majority of freed V/Os will possess velocities in excess of 0.67 cm per second. Therefore, even

at the 10^6 V/O per square foot level, it is probable that V/O contamination through B/B meteoroid holes will not produce P_C greater than 10^{-4} with the Case 4 assumptions. Additionally, the ability to guarantee P_C less than 10^{-4} can be enhanced considerably by a decontamination cycle (such as uv or ETO) on the T/B to reduce the V/O concentration on its surface prior to launch.